IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Application of: Alexandr Alexandrovich MIROSHIN et al.

Application # 09/367,543

Filed: 16 August 1999

For: "POLARIZER AND LIQUID CRYSTAL DISPLAY ELEMENT"

DECLARATION under 37 CFR 1.132

We, Sergey V. BELYAEV, Nikolay V. MALIMONENKO, Aleksandr A. MIROSHIN, Ir Gvon KHAN hereby declare that:

1. We are citizens of Russian Federation and our addresses are:

- A.A.MIROSHIN – Russia, 125502 Moscow, Petrozavodskaya str., 17/2-152;
- S.V.BELYAEV – Russia, 141700 Moscow region, Dolgoprudnyi, Patzaev str, 14 -77. (Permanent address); South Korea, Taejon, Yu Song-Gu, Do Ryong-Dong, 381-42, LG-apt. 6-201, (Current address);
- N.V.MALIMONENKO – Russia, 141730 Moscow region, Lobnya, Lenina str., 6/3-18, (Permanent address); South Korea, Taejon, Yu Song-Gu, Do Ryong-Dong, 381-42, LG-apt. 6-203, (Current address);
- Ir Gvon KHAN – Russia, 141700 Moscow region, Dolgoprudnyi, Patzaev str, 14-26.

2. We graduated from:

- A.A. MIROSHIN – Loumumba Friendship of Nations University in 1974;
- S.V. BELYAEV – Moscow Institute of Physical Technology in 1971;
- N.V.MALIMONENKO - Moscow Institute of Physical Technology in 1980;
- Ir Gvon KHAN – Moscow State University in 1973;

3. Qualifications:

- A.A.MIROSHIN – Ms.D., Physics & Mathematics;
- S.V. BELYAEV –Ph.D., D.Sc., Physics & Mathematics;
- N.V.MALIMONENKO – Ms.D., Physics & Mathematics;
- Ir Gvon KHAN – Ph.D., Chemistry.

4. We are working:

- A.A.MIROSHIN – from 1974 to 1977 in Moscow branch of NITI; from 1977 to 1979 in Loumumba Friendship of Nations University; from 1979 to 1986 in Science Research Technological Institute of Optical Devices; from 1986 to 2001 in State Scientific Center of Russian Federation "NIOPIK" as scientist, from 2001 to present time as Principal Research Engineer in Research Center of Space information system and technology of observation;

- S.V.BELYAEV - State Scientific Center of Russian Federation "**NIOPIK**" from 1974 to 1997 as leader scientist, Department Chief, Deputy Director; from 1998 to present time as inviting scientist at LG Chemical (Korea);
- N.V.MALIMONENKO - State Scientific Center of Russian Federation "**NIOPIK**" from 1980 to 1997 as scientist; from 1998 to present time as inviting scientist at LG Chemical (Korea);
- Ir Gvon KHAN – Central Scientific Research Paper Institute from 1977 to 1981 as senior research scientist; from 1981 to present time in State Scientific Center of Russian Federation "**NIOPIK**" as leader scientist, Department Chief;

5. Our practical work experience in the field of physics and chemistry of liquid crystal materials and dyes, also polarizers and displays on their ground:

- A.A.MIROSHIN – from 1986 to 2001;
- S.V.BELYAEV – from 1967 to present time;
- N.V.MALIMONENKO – from 1980 to present time;
- Ir Gvon KHAN – from 1973 to present time;

6. We are the co-authors of the invention disclosed in our Patent Application № 09/367,543, filed in August 16, 1999 "POLARIZER AND LIQUID CRYSTAL DISPLAY ELEMENT".
7. We have read the Examiner's decision and we are informed with this final rejection of claims 97-102, 135 as obvious over Gvon et al. (U.S. Pat. No. 5,739,296) in view of Okuzaki et al. (U.S. Pat. No. 5,712,024).
8. For the demonstration that claims 97-102, 135 of claimed invention are not obvious over Gvon et al. (U.S. Pat. No. 5,739,296) in view of Okuzaki et al. (U.S. Pat. No. 5,712,024) we have fulfilled the calculations of wavelength λ dependence of refractive index **n** for materials based on the dyes according to Gvon et al. with various value of index of absorption and different spectral position of band absorption. The results are presented in the Appendix to the Declaration.

   The calculations were executed on the basis of Kramers-Kronig formula, well known to the physicists [http://www.dur.ac.uk/stuart.brand/kramkro.pdf]. The same formula was used in the recited by Examiner patent Okuzaki et al. (Column 5, line 40). The results of calculations for dye #1 and dye #2 prepared on the base of Gvon's dyes are shown in Appendix to Declaration and demonstrate that, depending on the index of absorption and spectral position of band absorption, it is possible to receive both cases – the decreasing of refractive index as the wavelength increases, i.e. normal dispersion – for dye #1 (mixture of ammonium salts of following Gvon's dyes: dye Formula II (a), R=Ph – 40%, dye Formula V

– 40%, dye Formula VI – 10%, dye Formula I, R'=Cl – 10%, see US Patent 5,739,296) and the growing of refractive index as the wavelength increases, i.e. abnormal dispersion - for dye #2 (mixture of ammonium salts of following Gvon's dyes: dye Formula V – 15%, dye Formula III (a), R=$C_6H_4OCH_3$ – 30%, dye Formula VI – 15%, dye Formula I, R'=Cl – 40%, see US Patent 5,739,296).

Thus, the dyes under the patent Gvon et al. also can reveal both normal, and abnormal dispersion of refractive index.

Moreover it was shown experimentally, that the single dye Formula II (a), R=Ph from Gvon's patent, having a considerable absorption at 380 nm (lgε = 4.12) also reveals normal dispersion of refractive index (see Fig. 1-D).

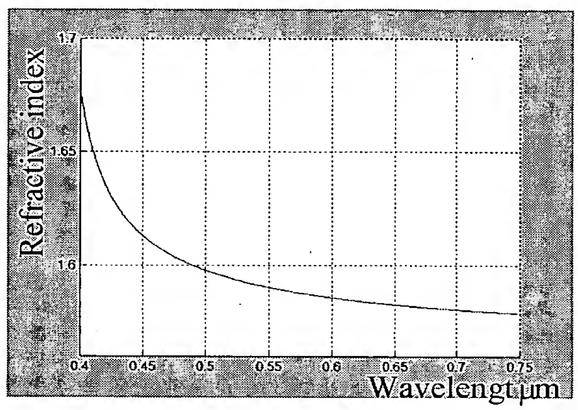
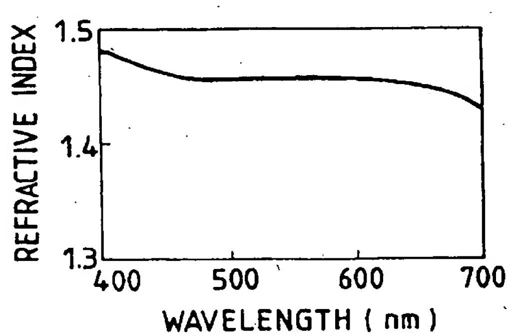


Fig. 1-D

Okuzaki et al. also used the materials based on the dyes providing not only the growing (abnormal dispersion), but the decreasing of refractive index as the wavelength increases at least at a certain range of the wavelengths spectrum, i.e. with normal dispersion. (See Fig. 12b of U.S. Pat. No. 5,712,024):

FIG. 12(b)



Thus, our results and data of patent Okuzaki et al. demonstrate that dye (coloring matter) having any absorption (isotropic or anisotropic) can provide either normal or abnormal dispersion, i.e. **not all** dyes reveal the feature of abnormal dispersion of refractive index. Therefore an anisotropic absorption is not sufficient condition for the revealing of abnormal dispersion of a refractive index in polarizing coating based on Gvon's dyes, which can reveal either normal or abnormal dispersion of refractive index.

In order to provide the abnormal dispersion the dyes must have a maximum index of absorption not less than 0.1 at least in the operating wavelengths range and suitable absorption spectrum (see Specification, page 11, lines 29-32 and Fig. 3-4 in Appendix to Declaration).

9. Applicants would like to remind that Gvon et al. teaches about anisotropic absorption (different absorption for different polarization of light, on the definition) only and does not mention about birefringence of layer. But Applicants would like to note that a priori birefringence of layer does not reveal without fail from the anisotropic absorption.

   The birefringence of oriented layers of dyes with anisotropic absorption was for the first time found and used by us in claimed invention.

   Moreover, Applicants would like to note that in the claimed invention namely besides birefringence the property of abnormal dispersion at least of one refractive index in anisotropic absorptive oriented layers of dyes, indicated in claim 135, was for the first time found and used by us for the preparation of different type of polarizers including interference polarizers based on birefringent anisotropic absorbing layer of certain thickness, whereat the interference extremum is realized at output of the polarizer at least for one light linearly-polarized component.

   According the claimed invention the employment of birefringent anisotropic absorbing layer with abnormal dispersion at least of one refractive index allows prepare high efficiency polarizers including polarizers utilizing more than 50% of the incident light energy and liquid crystal display.

   Applicants consider that all these polarizers are jointed by unity of invention based on the single element, namely on birefringent anisotropic absorbing layer with abnormal dispersion of at least one refractive index.

10. Thus the abovementioned data indicate that Gvon et al. (US Patent 5,739,296) and Okuzaki et al. (US 5,712,024), either individually or in combination, fail to disclose the polarizer based on birefringent anisotropic absorbing layer having abnormal dispersion at least of one refractive index since:

- Dyes (coloring matter) can reveal either normal or abnormal dispersion, i.e. not all dyes provide the feature of abnormal dispersion of refractive index;
- Selective absorption (different absorption light depending on wavelengths) is not sufficient for abnormal dispersion of refractive index;
- From the presence of anisotropic absorption only in any layer it is impossible to conclude a priori about the birefringence of this layer, and moreover about an abnormal dispersion of refractive index for said layer.
- Namely in claimed polarizer it was for the first time experimentally found and was used the property of abnormal dispersion at least of one refractive index in oriented layers of dichroic materials, for example, enumerated in claim 135. The property of abnormal dispersion for oriented layers of dichroic materials does not follow from previous theoretical background and not obvious to one of ordinary skill in the art.

Thus, the claimed polarizer and liquid crystal display have a favourable combination of properties, useful for practical applications. Such combination of properties is not obvious and can not be achieved by any of the referenced technical solutions both separately and in combination.

The achieved combination of properties for polarizers and liquid crystal display according to the invention is not obvious, because it can not be predicted on the basis of the existing theories, it is impossible to foresee it, it was obtained unexpectedly as a result of experiments.

11. We further declare, that all statements made herein of our own knowledge are true and that all statements made on information and belief are believed to be true; and father that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

Signature		Date
[signature]	A.A.MIROSHIN	04.04.03
[signature]	S.V.BELYAEV	08.04.03
[signature]	N.V.MALIMONENKO	08.04.03
[signature]	Ir Gvon KHAN	09/04/03

Calculation of refractive index vs. wavelength of light for colored materials with various absorption vs. wavelength

1. Theoretical background :

To calculate refractive index vs. wavelength of light for colored materials with various absorption coefficients we have used known Kramers-Kronig relation:

$$n(\omega) = n_\infty + \frac{2}{\pi} \cdot \int_0^\infty \frac{\Omega \cdot k(\Omega)}{\Omega^2 - \omega^2} \cdot d\Omega$$

where $n(\omega)$ - a refractive index at wave frequency ω;

n_∞ - a refractive index of material which does not contain any coloring dye;

$k(\Omega)$ - an absorption coefficient

If we change $\Omega = \frac{2 \cdot \pi}{\lambda}$ and $\omega = \frac{2 \cdot \pi}{\lambda_0}$ we receive more convenient notation for calculation:

$$n(\lambda_0) = n_\infty + \frac{1}{2 \cdot \pi^2} \cdot \int_0^\infty \frac{\alpha(\lambda)}{1 - \frac{\lambda^2}{\lambda_0^2}} \cdot d\lambda$$

, where $\alpha(\lambda) = \frac{4 \cdot \pi \cdot k(\lambda)}{\lambda}$ - absorbance , used in Buger-Lambert-Ber law for light absorbing material layer transmission $T = e^{-\alpha(\lambda)d} = 10^{-\varepsilon(\lambda)d}$, where $\varepsilon(\lambda)$ - extinction, d - thickness of layer)

2. Calculation results

Fig.1 Absorbance α and extinction ε for dye #1 versus wavelength

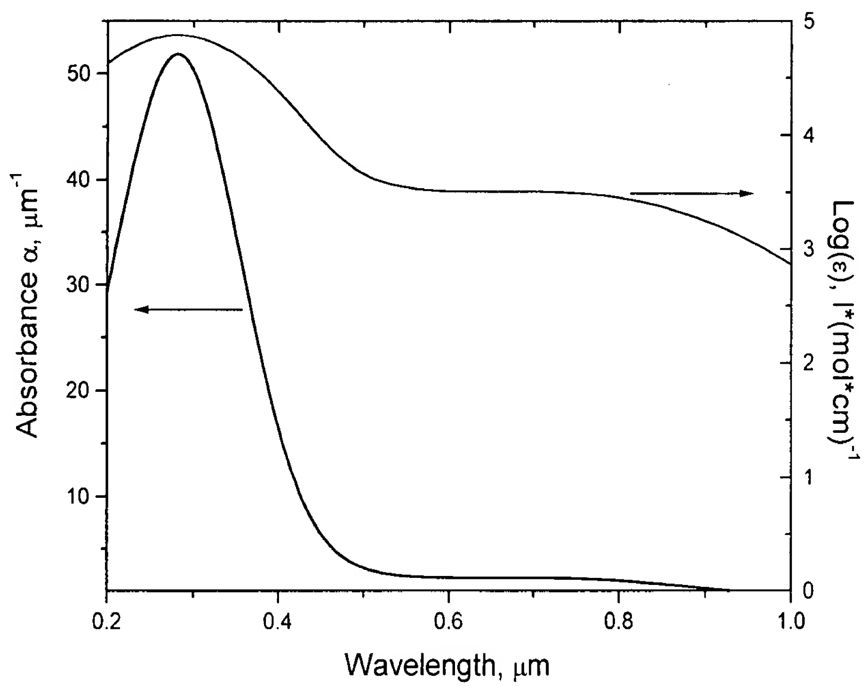
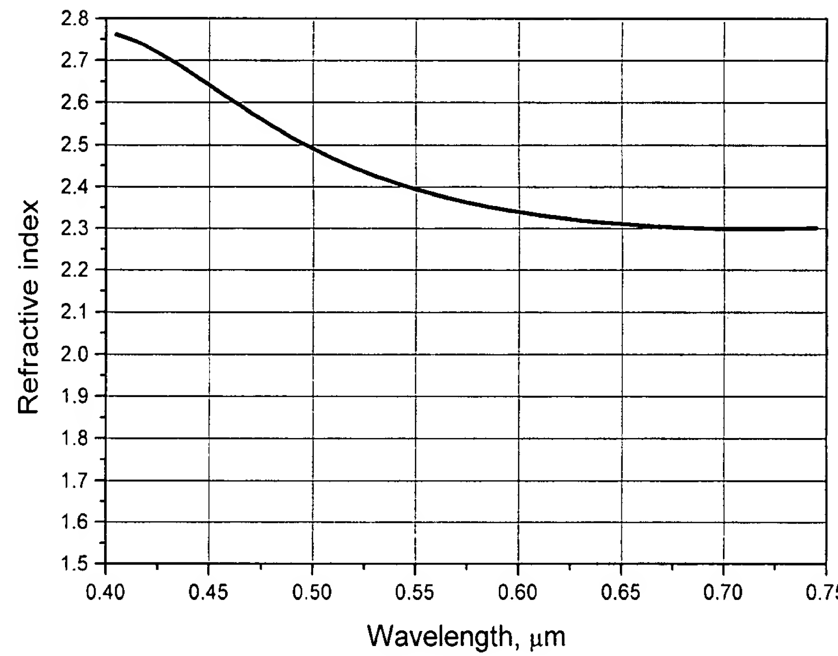


Fig.2 Refractive index vs. wavelength for dye #1



Refractive index vs. wavelength of light for colored material (dye #1).

Normal dispersion case.

Fig.3 Absorbance α and extinction ε for dye #2 versus wavelength

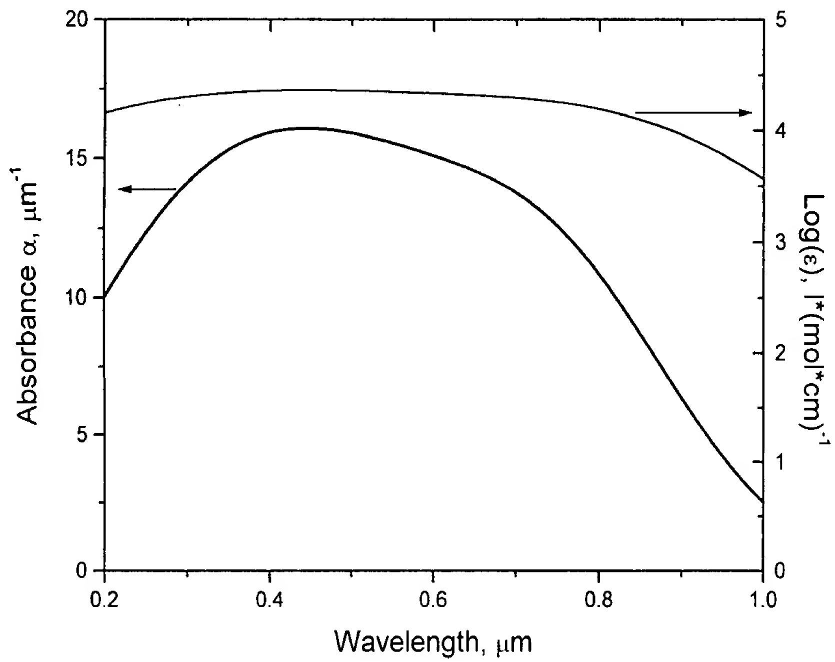
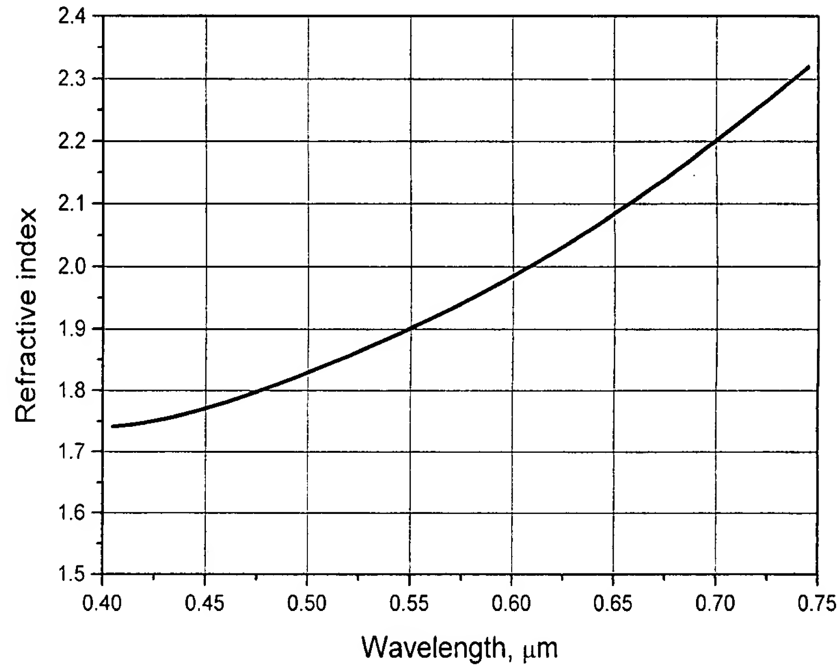


Fig.4 Refractive index vs. wavelength for dye # 2



Refractive index vs. wavelength of light for colored material (dye # 2).

Abnormal dispersion case

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Reg. No. 20/14-496(2) September 21, 1999

THIS IS TO CERTIFY

By Federal Institute for Industrial Property of Russian Agency for Patents and Trademarks that the materials appended hereto are the exact reproduction of the original specification, claims and drawings (if any) of Application No. 98101616 for patent on invention as filed on the 12th day of January, 1998.

Title of the invention: An optical polarizer

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Actual author(s): BELYA'YEV Serghey Vasil'yevich
MALIMONENKO Nikolay Vladimirovich
MIROSHIN Alexandr Alexandrovich

Authorized signer of the copy of
application for patent on invention
/signature/
G.F. Vostrikov
Head of Division

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AN OPTICAL POLARIZER

The invention relates to optics, particularly, to optical polarizers, that can be suitably used in liquid-crystal displays, polarizing spectacles, motor cars and other transportation means, as well as in glass used in construction, lighting fixtures and optical instruments.

The presently used optical polarizers are represented by a polymer film, oriented by uniaxial extension, dyed in mass by dichroic organic dyes or iodine compounds. As a polymer, polyvinyl alcohol (PVA) [1] is mainly used. Iodine PVA-based polarizers, dyed with iodine, have the highest polarizing characteristics and are extensively used in manufacture of liquid-crystal indicators for watches, calculators, portable computer screens, etc.

When the non-polarized light passes through a dichroic optical polarizer [1], of linearly-polarized component, whose oscillation plane is parallel to the absorption plane, is absorbed practically completely. The other orthogonal linearly-polarized component, i.e. the component wherein the oscillation plane is perpendicular to the absorption axis, passes through an optical polarizer, thereby being subjected to a significantly lesser absorption. Thus polarization of the passing light takes place. The iodine polarizers are multi-layer films that comprise, apart from the polarizing layer, the reinforcing, gluing and protections layers.

Disadvantages of said film-shaped dichroic polarizers, besides their comparatively high cost caused by a complexity of manufacture thereof, are their low thermal and light resistance.

The analog of the claimed optical polarizer can be also a dichroic light polarizer (DLP) representing a substrate, whereon applied is a thin film of a molecularly-arranged layer of dichroic dyes being sulfonic acids or their non-organic salts of aso- and polycyclic compounds, or their mixes, capable of forming a stable lyotropic liquid crystals (LLC) and compositions based thereon [2].

For manufacture of the known polarizer [2]: dyes are applied on the substrate surface, with simultaneous mechanical orienting thereof, with subsequent evaporation of a solvent. Thereby on the substrate surface formed is a film 0.1-1.5 mcm thick of a

molecularly-arranged layer of a dye - a polarizing coating (PC) capable of polarizing the light.

The known polarizer [2] has an higher thermal and light resistance as compared with the iodine polarizers, but has lower polarizing characteristics.

Also known are optical polarizers that «work» owing to other physical phenomena, e.g. owing to different light reflection index, having different polarizations. Polarizers of such type are referred to as the reflection-type polarizers, and therein the light polarization phenomena are utilized both in incidence and reflection of light beams from the surface of any dielectric materials at inclined angles approximating Brewster angle, and in the normal (perpendicular to the surface) incidence and reflection of light from the surface of birefringent materials. An improvement of the polarizing properties achieved in using the multi-layer design of the reflection-type polarizers.

The most pertinent prior art is the known polarizer [3], comprising at least one birefringent layer with a thickness whereat an interference extremum at output of the optical polarizer is realized for at least one linearly-polarized light component. Such polarizer includes interleaved layers of two *transparent* (non-absorbing in the operation wavelength range) polymeric materials, of which at least one is the birefringent layer. Birefringence in said polymeric material is created as a result of extending of a film, manufactured of said material, in single direction 2-10 times. The other layer of the polymeric material, interleaved layer-by-layer with the birefringent layer, is the optically isotropic layer. The ordinary refractive index of the birefringent layer is equal to that of the optically isotropic layer. The extraordinary refractive index of the birefringent layer differs from that of the optically isotropic layer.

The operation principle of the known optical polarizer is based on that, one linearly-polarized component of the non-polarized light, to which component corresponds the extraordinary (greater) refractive index of the birefringent layer, is essentially reflected from the multi-layer optical polarizer due to a difference of refractive indices on boundaries of the birefringent and the optically isotropic layers. When thicknesses of layers is about the light wavelength magnitude, the light beams reflected from the layers boundaries, interfere with one another. When thicknesses of layers and their refractive indices are appropriately selected, the optical travel difference between the waves reflected from the layers' boundaries is an integer of wavelengths, i.e. the result of interference of

the reflected waves will be the interference maximum resulting in their mutual amplification. In this case, reflection of the linearly-polarized component of the non-polarized light, to which component corresponds the extraordinary (greater) refractive index of the birefringent layer, is amplified considerably.

The ordinary (lesser) refractive index of the birefringent layer is selected to be essentially equal to refractive index of the optically isotropic polymeric layer, i.e. there is no difference (abrupt changes) of refractive indices on boundaries of the birefringent and the optically isotropic layers. For this reason, the other linearly-polarized component of the incident non-polarized light, to which component the ordinary (lesser) refractive index of the birefringent layer corresponds, passes through the multi-layer polarizer completely, without any reflections.

Thus, when the non-polarized light is incident on the known optical polarizer, one linearly-polarized component is reflected, and the other linearly-polarized component passes through the polarizer, i.e. polarization of light both for the passing and the reflected light takes place.

The known optical polarizer [3] is a combined one and further comprises a dichroic polarizer having a weak absorption and dichroism, optically positioned with a reflection-type optical polarizer. The role of an additional dichroic polarizer, whose transmission axis is parallel to that of the reflection-type optical polarizer is elimination of reflections of the external light when the combined optical polarizer operates «for translucency».

One of the disadvantages of the known optical polarizer is comparatively strong spectral dependency of its optical characteristics, i. e., dependency of the polarizing capability and reflection (and transmission) index on the polarized light wavelength. This disadvantage is caused by the fact that refractive indices in the used materials decrease as the polarized light wavelength grows.

The other disadvantage of the known optical polarizer [3] is the necessity to use a great amount of interleaved layers, which necessity is caused by the fact that the maximum value of birefringence (difference between the extraordinary and ordinary refractive indices of a birefringent material) in transparent polymer materials is small and generally does not exceed 0.1-0.2. Therefore the index of the reflection from boundaries of layers is small, and to produce an high reflection, in the whole, of an optical polarizer it is

necessary to use a great number (100-600) of layers which is a rather difficult task and requires a special precision equipment.

The second reason of the necessity to use a great number of layers in the prototype optical polarizer is as follows. To polarize light in a broad spectrum of wavelength in a multi-layer coating, many pairs of interleaved layers or pair groups having different thickness for the purpose to «tune» each pair group to the «own» wavelength of a broad spectrum range is required.

However, even when a great number of layers' pair groups is used, each of which being tuned to its own wavelength, the optical characteristics of the known polarizer have a comparatively strong dependence on the polarized light wavelength.

The goal of the invention is to provide an optical polarizer ensuring high polarization characteristics in a broad spectrum range using a number of layers not more than 10 layers.

The set goal is to be attained in an optical polarizer characterized in that at least one birefringent layer is anisotropically absorbing one and the other has at least one refractive index that increases as the polarized light wavelength grows at least in a range of the operation wavelengths.

The essential feature of the invention is at least one birefringent layer having a thickness wherein one interference extremum is realized at output of the optical polarizer at least for one linearly-polarized light component. Thickness of the birefringent layer is selected also as a function of the type of the material used for manufacture of a layer.

The distinguishing feature of the invention is at least one anisotropically absorbing birefringent light having at least one refractive index that increases as the polarized light wavelength grows. Thereby, first, value of at least one refractive index significantly increases, and the required number of layers abruptly diminishes. Second, dependence of the conditions of obtaining the interference extrema (maximums and minimums) on the light wavelength is reduced, and in the optimum version the same is eliminated completely, which circumstance provides high polarization characteristics of the optical polarizer in a broad spectrum range.

Versions of embodiment of the optical polarizer according to the invention, characterized in that at least one birefringent layer is the anisotropically absorbing one and

has at least one refractive index that increases as the polarized light wavelength grows in at least some range of the operation wavelengths are as follows:

1. An optical polarizer characterized in that at least one anisotropically absorbing birefringent layer is made of a material selected among low-molecular thermotropic liquid-crystal materials or their mixtures, being dichroic dyes and comprising, as a component, liquid-crystal and/or non-liquid crystal dichroic dyes.
2. . An optical polarizer characterized in that at least one anisotropically absorbing birefringent layer is made of a material selected among polymeric thermotropic liquid-crystal or non-liquid-crystal substances or their mixtures, comprising the solved in water and/or chemically bonded with a polymer chain dichroic dyes, is less than 0.2 mcm thick.
3. . An optical polarizer characterized in that at least one anisotropically absorbing birefringent layer being an oriented film of non-liquid-crystal polymeric materials with a controlled degree of hydrophilicity, dyed with dichroic dyes and/or iodine compounds.
4. . An optical polarizer characterized in that at least one anisotropically absorbing birefringent layer is formed of dichroic organic dyes of the polymeric structure.
5. . An optical polarizer characterized in that at least one anisotropically absorbing birefringent layer is an oriented molecularly-arranged layer of organic salts of dichroic anionic dyes.
6. . An optical polarizer characterized in that at least one anisotropically absorbing birefringent layer is an oriented molecularly-arranged layer less than 0.1 mcm thick of dichroic dyes capable of forming a lyotropic liquid-crystal phase.
7. An optical polarizer characterized in that at least one anisotropically absorbing birefringent layer is an oriented molecularly-arranged layer less than 0.1 mcm thick of dichroic dyes of the polymeric structure capable of forming a lyotropic liquid-crystal phase.
8. An optical polarizer characterized in that at least one anisotropically absorbing birefringent layer is an oriented molecularly-arranged layer less than 0.1 mcm thick of dichroic dyes or their mixtures capable of forming a stable lyotropic liquid-crystal phase.

The above-discussed versions do not limit the possibilities to use other materials in forming anisotropically absorbing birefringent layers for the proposed optical polarizer.

An anisotropically absorbing birefringent layer in the proposed optical polarizer can be both solid and liquid.

The use of at least one anisotropically absorbing birefringent layer, though causing slight light losses in the polarizer, but these losses are small, particularly in the layers having thickness less than 0.1 mcm, and the attained technical result is high polarization characteristics in a broad spectrum range when at most 10 layers are used, and this result compensates for these losses.

Selection of techniques for manufacture of the optical polarizer of the invention depends on the type of the materials used for anisotropically absorbing birefringent layers and other layers, and it does not affect the essence of the invention.

For forming anisotropically absorbing birefringent layers the following standard methods can be used: application by a roller, doctor blade, blade in the form of non-rotating cylinder, application using a sheet die. In a number of case, after application a layer is subjected to drying for the purpose to remove solvents. In other cases, for example for thermoplastic polymer materials and vitrified materials, the applied layer is cooled after application.

The other methods that can be used for producing anisotropically absorbing birefringent layers of the materials formed in the course of application of a liquid-crystal phase, is application of this material on the substrate initially prepared for orientation of the liquid-crystal phase [4]. One of these techniques is the unidirectional rubbing of the substrate, known and used for orienting thermotropic low-molecular liquid-crystal mixes in manufacture of LC-displays.

Another technique for producing anisotropically absorbing birefringent layers is the known technique of photo-orientation of the preliminarily applied, in this or other way, layer using irradiation of the same by ultra-violet light.

For application of anisotropically absorbing birefringent layers of thermotropic polymer materials, extruders can be used, inclusive of those having several sheet dies and allowing to apply in one run several layers of different polymeric materials of a required thickness.

Here and hereinafter the notions of «light» and «optical» (polarizer) mean the electromagnetic radiation of the visible, near ultraviolet and near infrared wavelength ranges, i.e. that of 250-300 nm to 1000-2000 nm (0.25-0,3 to 1-2 micrometers).

Here and hereinafter a planar layer is cited solely for the purpose of a more ready understanding. Without prejudice to the generality, we mean also an optical polarizer having diverse shapes: cylindrical, spherical and more complex shapes. Further, the proposed polarizer can be implemented both as structurally single and isolated, and as applied on various substrates or between substrates.

Layers having at least two different refractive indices: the extraordinary index n_e for one linearly-polarized light component, and the ordinary index n_o for the other orthogonal linearly-polarized light component, are referred to a the birefringent ones. Value $\Delta n = n_e - n_o$ is referred to as anisotropy of the refractive index, or simply the optical anisotropy. Here and hereinafter its is assumed that the optical axes, to which axes the extraordinary and ordinary are orthogonal and disposed in the layer plane. The optical axis, to which axis the extraordinary refractive index n_e corresponds, is defined by this or other way. For example, such axis can be the direction in which a polymer material has been drawn, or a director in an oriented nematic liquid crystal. Such birefringent layer in sense of crystal optics corresponds to an optically uniaxial plate, cut in parallel to the main axis. Here and hereinafter, as an example, considered are the optically positive birefringent layers, wherein $n_e > n_o$. Without prejudice to the generality, all inferences also belong to the optically negative birefringent layers, wherein $n_e < n_o$.

In a more general case, for example for the optically biaxial layers, there are three different refractive indices $n_x = n_e$, $n_y = n_o$, n_z. Refractive index n_x corresponds to the direction of oscillations in a light wave, which direction is parallel to the layer plane and directed along direction X, somehow defined, in the layer plane, and also corresponds to the following directions: n_y - direction of Y-oscillations in a light wave, also parallel to the layer plane, but perpendicular to X-direction, n_z - direction of Z-oscillations in a light wave that is perpendicular to the layer plane. Depending on a method for manufacturing the birefringent layers and a type of the used materials, ratio of refractive indices values n_x , n_y , n_z can be different.

In the proposed polarizer at least one anisotropically absorbing birefringent layer can have one, two or all the three refractive indices that grow as the polarized light wavelength increases at least in some range of the operation wavelengths.

The most preferable is the use of the optical polarizer according to the invention characterized in that at least one anisotropically absorbing birefringent layer has at least one refractive index that is directly proportional to the polarized light wavelength in some range of the operation wavelengths. Thus, if in formula $2dn_e = m\lambda$ (where d is thickness of the anisotropically absorbing birefringent layer, m is the interference order) that corresponds to the interference maximum condition, the extraordinary refractive index n_e will be directly proportional with the light wavelength, i.e. $n_e = A\lambda$ (where A - proportionality coefficient), then wavelength λ «decreases», and this means that the condition of the interference maximum, in this case, is satisfied for all wavelengths and, moreover, for all interference orders, i.e. for all values of m. Further, when the layer thickness of the same material has other values, the independence from the light wavelength of the interference minimum condition can be similarly provided. The direct proportionality of the refractive index with the light wavelength is a more strict requirement (condition), than a simple increase of the refractive index as the light wavelength grows.

According to the invention, preferable is an optical polarizer, characterized in that at least one anisotropically absorbing birefringent layer has the maximal value for at least one refractive index not less than 1.9. In this case the necessary number of layers does not exceed 10 layers, and the spectrum range having the high polarizing characteristics broadens more than thrice as compared with the prototype.

Experiments and estimates have also demonstrated that preferable is an optical polarizer, characterized in that at least one anisotropically absorbing birefringent layer has the maximal absorption index not less than 0.1 in the operation wavelength range.

The optimal polarizer is the one characterized in that thickness of anisotropically absorbing birefringent layer are selected for the purpose to satisfy the condition of obtaining at output of the optical polarizer the interference minimum for one linearly-polarized light component and, simultaneously, the interference maximum for the other orthogonal linearly-polarized light component. Actually, the distinguishing feature of the birefringent layers is the mere fact of the presence of at least two different values of

refractive indices, e.g. n_x and n_y, corresponding to axes X and Y disposed in the layer plane. Owing to this circumstance, the layer thickness and the interference order (number m) can be selected such that at output of the polarizer there will be obtained the interference minimum for one linearly-polarized component, and simultaneously, the interference maximum for the other orthogonal linearly-polarized light component. The interference minimum can correspond to the ordinary refractive index, whereby the interference maximum is caused, accordingly, by the extraordinary refractive index. Also possible is the reverse situation, when the interference minimum corresponds to the extraordinary refractive index, whereby the interference maximum is caused, accordingly, by the ordinary refractive index.

Also preferable is the polarizer characterized in comprising at least two layers, of which at least one layer is the anisotropically absorbing birefringent layer, and the other is the optically isotropic one, one refractive index of the birefringent layer maximally differing from that of the optically isotropic one, and the other refractive index of the anisotropically absorbing birefringent layer coinciding with, or being maximally proximate to that of the optically isotropic one.

In this version, one linearly-polarized component of the incident non-polarized light, to which component corresponds the extraordinary (greater) refractive index of the anisotropically absorbing birefringent layer, is essentially reflected from the multi-layer polarizer due to a difference between refractive indices on the boundaries of the layers. When thicknesses of layers and their refractive indices are appropriately selected, the optical travel difference between the waves reflected from boundaries of the same anisotropically absorbing birefringent layer is an integer of wavelengths, i.e. the result of their interference will be the interference maximum resulting in the mutual amplification of the reflected waves. In this case the optical thicknesses of the optically isotropic material layers can be both significantly greater than the wavelength, and approximately equaling the wavelength. As the result, reflection of the linearly-polarized component of the non-polarized light, to which component corresponds the extraordinary (greater) refractive index of the anisotropically absorbing birefringent layers, is amplified considerably.

The ordinary (lesser) refractive index of the anisotropically absorbing birefringent layers coincides with, or maximally is proximate to the refractive index of the optically

isotropic layer, i.e. there is no difference (abrupt changes) of the refractive indices on the layer's boundaries. For this reason, the other linearly-polarized component of the incident non-polarized light, to which component the ordinary (lesser) component of refractive index of the birefringent layer corresponds, passes through the multi-layer polarizer completely, without any reflections.

The other version of the invention is an optical polarizer, characterized in comprising at least two different birefringent layers, of which at least one is the anisotropically absorbing birefringent layer, one refractive index of the anisotropically absorbing birefringent layer maximally differs from one refractive index of the other birefringent layer, and the other refractive index of the anisotropically absorbing birefringent layer coincides with, or is maximally proximate to the refractive index of the other birefringent layer.

The interference result is strongly influenced by ratio of intensities, and hence the ratio of amplitudes of the electric fields of the interfering rays. It is known that the minimum value of intensity in the interference minimum (being zero, in theory) can be obtained in case of their equality. Therefore it is advisable to provide the maximal possible equalization of amplitudes of the interfering rays for the interference minimum condition, which ensures the maximal «blanking» of rays of the corresponding component of the non-polarized light. To obtain the optimal interference result for the interference maximum condition, indices of reflection from each of the layer boundaries must be increased.

The proposed optical polarizer can be implemented to operate both «for reflection» and «transmission», and also to operate only «for reflection». In these cases, the embodiment is a polarizer characterised in that on one of its sides additionally applied is a light-reflecting coating. Preferable is a polarizer, wherein the light-reflecting coating is the metallic one. Application of the light-reflecting coating also allows to select the optimal, for the interference, indices of reflection from the optical polarizer's boundaries.

When the optical polarizer is applied on a substrate: as the first coating on the substrate side, both the light-reflecting coating (a mirror of the complete or partial reflection), and the optical polarizer itself can be applied.

The reflecting coating can be implemented both of a metal, and in the form of multi-layer dielectric mirrors made of interleaved layers of the materials having high and low refractive indices.

Metallic coatings are applied sufficiently simply by, for example, thermal vacuum evaporation, but in this case absorption of light takes place in such coatings, which decreases the transmission (reflection) properties of the polarizer. For producing the reflecting metallic coatings, aluminium (Al), silver (Ag) and other metals can be used.

In the case of multi-layer dielectric mirrors, absorption of light does not take place therein, but the process of their application is rather complicated and labour-intensive. The following materials can be used for such coatings: TiO_2, MgO, ZnS, ZnSe, ZrO_2, cryolite and polymers - as the materials having an high refractive index; and SiO_2, Al_2O_3, CaF_3, BaF_2, MgF_2, AlN, BN or polymers - as the materials having a low refractive index.

The following standard methods can be used for applying the reflecting coatings upon a substrate or an optical polarizer: thermal vacuum evaporation, vapour application with subsequent thermal treatment, magnetronic spraying an other methods.

As the substrate material, whereon an optical polarizer operating for «translucency» and, possibly, for «reflection» can be applied, any materials that are transparent in the operation wavelength range, e.g. quartz, glass, polymers and other, can be used.

As the substrate material, whereon the optical polarizer can be applied to operate only «for reflection», besides the materials that are transparent in the operation wavelength range, e.g. quartz, glass, polymers, also any other materials that are opaque in the operation wavelength range, e.g. metals, semiconductor materials, glass ceramic, plastics and other can be used.

The invention is illustrated as separate examples of particular embodiments in Figs. 1-3. Fig. 1 shows a diagram of an one-layer, reflection-type polarizer according to the invention. Fig. 2 schematically shows types of the dependencies of the refractive index of the optical polarizers on the light wavelength. Fig. 3 shows a diagram of a multi-layer optical polarizer according to the invention.

Fig. 1 shows a diagram of an one-layer reflection-type optical polarizer according to the invention, comprising anisotropically absorbing birefringent layer 1, characterised in that both its refractive indices (extraordinary n_e and ordinary n_o) are proportional to the polarized light wavelength. In the most simple version, layer 1 from two sides is bounded on air. In more sophisticated versions, on one of its sides additionally applied is a light-

reflecting coating. Layer 1 can be applied also on the substrate of, for example, a transparent glass (shown by dashed line in Fig 1).

Operation of the proposed reflection-type polarizer can be explained as follows. Non-polarized light consists of two linearly-polarized components 2 and 3, whose polarization planes are mutually perpendicular (these two components in Fig. 1 are conventionally separated for the illustrative purposes and a more ready understanding). Component 2, polarized in parallel to the optical axis of layer 1 of an anisotropically absorbing birefringent material, is partially reflected from boundary of layer 1, thereby forming ray 4. The partial reflection of light from the interface of layer 1 and the environment takes place due to an abrupt change (difference) of refractive indices on this interface. For the partial reflection of the light, also an additionally applied light-reflecting coating on layer 1 can be used. The other portion of energy of component 2, passing through the anisotropically absorbing birefringent layer 1 is reflected from the second boundary of layer 1, and passes once again through layer 1, thereby forming ray 5. The reflected rays 4 and 5 are polarized in the same way as incoming component 2.

Thickness of layer 1 is selected such that the optical difference of travel Δ_e for rays 4 and 5, corresponding to the greater refractive index n_e will be an odd number of half-waves of the polarized light, $\Delta_e = \lambda/2 + m\lambda$, where λ is light wavelength, m is interference order. If environments at either side of layer 1 are transparent (non-absorbing) and have the refractive indices that are less than refractive indices of layer 1, then the optical difference of travel is $\Delta_e = 2dn_e + \lambda/2$, where d is thickness of layer 1, and $\lambda/2$ is a phase abrupt change in reflection from the first boundary as from the optically more dense medium. In this case, the result of interference of rays 4 and 5 is their mutual attenuation, and in the optimum version their complete blanking takes place. The complete blanking of rays 4 and 5 is achieved when intensities (amplitudes) of rays 4 and 5 are identical or approximate one another, which can be attained by the optimal selection of indices of reflection from boundaries of layer 1 using, for example, an additionally applied light-reflecting coating. The light-reflecting coating can be a metallic or dielectric one, and one-layer or multi-layer one. When the condition of proportionality of the extraordinary refractive index of the anisotropically absorbing birefringent layer 1 to the light wavelength being ($n_e \approx \lambda$) is satisfied, the equality of $\Delta_e = 2dn_e + \lambda/2 = \lambda/2 + m\lambda$ is

satisfied for the whole range of the operation light wavelengths, which provides high polarization characteristics in a broad spectrum range.

The other linearly-polarized component 3 that is polarized perpendicularly to the optical axis of the anisotropically absorbing birefringent layer 1, is partially reflected from the first boundary of layer 1, thereby forming ray 6. The other portion of energy of component 3, passing through layer 1 is reflected from the second boundary of layer 1, passes once again through layer 1, thereby forming ray 7. The reflected rays 6 and 7 are polarized in the same way as incoming component 3. The result of interference of rays 6 and 7 is their mutual amplification, i.e. the interference maximum, for the optical difference of the travel between them Δ_o, that corresponds to the ordinary (lesser) refractive index n_o is an integer of wavelengths $\Delta_o = 2dn_o + \lambda/2 = m\lambda$ (phase' abrupt change $\lambda/2$ when ray 6 is reflected from the first boundary of layer 1 also takes place for this component). When the condition of proportionality of the ordinary refractive index of the anisotropically absorbing birefringent layer 1 to the light wavelength ($n_o \approx \lambda$) is satisfied, the interference maximum condition $\Delta_o = 2dn_o + \lambda/2 = m\lambda$ is also satisfied for the whole range of the operation light wavelengths, which means the elimination of the spectral dependency of the polarization characteristics of the optical polarizer.

Thus in a broad region of spectrum, as a result of the interference, the total reflection of component 2, that is polarized in parallel to the optical axis of layer 1 of the birefringent material, is significantly less than reflection of component 3 that is polarized perpendicularly to the optical axis of layer 1.

Also possible the reverse situation, when as a result of the interference the total reflection of component 2, that is polarized in parallel to the optical axis of the birefringent material layer 1, is significantly greater than reflection of component 3 that is polarized perpendicularly to the optical axis of layer 1. Such situation takes place when thickness of layer 1 is selected such that the optical difference of travel Δ_e for rays 4 and 5, that corresponds to the extraordinary (greater) refractive index n_e, will be an even number of half-waves of the polarized light $\Delta_e = m\lambda$. In this case, the result of interference of rays 4 and 5 is the interference maximum, i.e. their mutual amplification. At the same time, the optical difference of travel Δ_o for rays 6 and 7, that corresponds to the ordinary (lesser) refractive index n_o, is an odd number of half-waves of the polarized light $\Delta_o = \lambda/2 + m\lambda$. In this case, the interference result of rays 9 and 10 is the interference minimum, i.e.

their mutual attenuation. Now, as the interference result, the total reflection of component 2, that is polarized in parallel to the optical axis of layer 1 of the birefringent material, is significantly larger ~~lower~~, than reflection of component 3 that is polarized perpendicularly to the optical axis of layer 1 of the birefringent material.

Fig. 2 schematically shows the dependencies of refractive index of layers in optical polarizers on the visible light wavelength, i.e. in the range of 400-700 nm. Curve 1 corresponds to the optical polarizer of the prototype, wherein the refractive index of layers decreases as the light wavelength grows. Such dependency in optics is referred to as the normal dispersion and is intrinsic to transparent materials. Curve 2 corresponds to the optical polarizer according to the invention, wherein at least one refractive index of layers increases as the light wavelength grows. Such dependency in optics is referred to as the abnormal dispersion, and the optical polarizer must have a particular design so that to obtain such dependency. Experiments and estimates have shown that for this purpose preferable is a polarizer, characterised in that at least one anisotropically absorbing birefringent layer has the maximum absorption index of not less than 0.1 in the operation wavelength range. Here, as in optics, the absorption index of the manufactured layer k is determined (as in GOST 7601-78 standard) as the index at the virtual portion in the integrated refractive index of the manufactured material layer $Z = n - ik$. Curve 3 corresponds to the preferable embodiment of the optical polarizer according to the invention, characterised in that at least one anisotropically absorbing birefringent layer has at least one refractive index directly proportional with the polarized light wavelength at least in some operation wavelength range. The direct proportionality of refractive index to the light wavelength is a more strict requirement (condition) than a simple increase of refractive index when the light wavelength grows. High polarization characteristics in a broad spectrum range are provided in the optical polarizer, characterized in that the refractive index increases as the polarized light wavelength grows both in some range of the operation wavelengths, and in all operations wavelengths.

Fig. 3 shows a diagram of a multi-layer optical polarizer according to the invention, comprising 4 anisotropically absorbing birefringent layers 1, characterised in that the extraordinary refractive index n_e of these layers increases as the polarized light wavelength grows. Said layers 1 are applied as interleaved with four layers 8 of an optically isotropic material, the ordinary refractive index n_o of the birefringent material coinciding with, or

maximally proximate to refractive index n_i of the optically isotropic material. Anisotropically absorbing birefringent layers 1 can be implemented of identical or different materials, differing, for example, in spectral ranges, wherein the extraordinary refractive index n_e increases as the wavelength grows.

Operation of the proposed optical polarizer can be explained as follows. Non-polarized light consists of two linearly-polarized components 2 and 3, whose polarization planes are mutually perpendicular (these two components are conventionally separated in Fig. 3 for the illustrative purpose and a more ready understanding). Component 2 that is polarized in parallel to the optical axis of the anisotropically absorbing birefringent layers 1 is partially reflected from boundaries of layers 1 and optically isotropic layers 8, thereby forming rays 4. Reflected rays 4 are polarized in the same way as incoming component 2.

Thickness of layers 1 is selected such that the result of interference of all rays 4 is the interference maximum, i.e. their mutual amplification. Thereby reflection index reaches 98%-99.9%, which means that linearly-polarized component 2 practically completely is reflected from the polarizer, thereby forming ray 9. When a condition more strict that a simple increase, namely the condition of the direct proportionality of the extraordinary refractive index of the anisotropically absorbing birefringent layers 1 to the light wavelength ($n_e \approx \lambda$) is satisfied, the interference maximum condition is satisfied for a more broad range of wavelengths propagating over the whole operation light wavelengths range.

To the other component 3 of the non-polarized light that is linearly-polarized perpendicularly to the optical axis of layers 1, corresponds the ordinary refractive index n_o of layers 1, that is equal to refractive index n_i of the optically isotropic layer ($n_o = n_i$). Here there is no reflection from boundaries of layers 1 and 8, and linearly-polarized component 3 passes through a multi-layer polarizer completely, without any reflections, thereby forming ray 10. Reflection of component 3 from the external surfaces of the polarizer can be eliminated by an usual method of «brightening», i.e. by application of optically isotropic layers, having the optical thickness of the quarter of the wavelength and refractive index of $n_o^{1/2}$, on the external surfaces.

Thus, the non-polarized light when being incident upon the multi-layer optical polarizer is divided into two parts and converted into linearly-polarized ray 9 that passes

through the polarizer, and orthogonally linearly-polarized ray 10 that is reflected from the polarizer.

The above-described examples do not limit possible versions of the particular embodiments of the proposed optical polarizer.

Thus, in all above-discussed examples, provided are high polarization characteristics of the optical polarizer in a broad spectrum range, when the number of the used lays does not exceed 10.

CLAIMS

1. An optical polarizer, including at least one anisotropically absorbing birefringent layer having a thickness, whereat an interference extremum at output of the optical polarizer at least for one linearly-polarized light component is realized, characterized in that at least one birefringent layer is the anisotropically absorbing one and has at least one refractive index that increases as the polarized light wavelength grows at least in some range of the operation wavelengths.
2. The optical polarizer as claimed in claim 1, characterized in that at least one anisotropically absorbing birefringent layer is made of a material selected among low-molecular thermotropic liquid-crystal substances or their mixtures, being dichroic dyes or comprising, as a component, liquid-crystal and/or non-liquid-crystal dichroic dyes.
3. The optical polarizer as claimed in claim 1, characterized in that at least one anisotropically absorbing birefringent layer is made of a material selected among polymeric thermotropic liquid-crystal or non-liquid-crystal substances or their mixtures, comprising the solved in water in mass and/or chemically bonded with a polymeric chain dichroic dyes, and is less than 0.2 mcm thick.
4. The optical polarizer as claimed in claim 1, characterized in that at least one anisotropically absorbing birefringent layer is the oriented film of non-liquid-crystal polymeric materials having a controlled degree of hydrophilicity, dyed with dichroic dyes and/or iodine compounds.
5. The optical polarizer as claimed in claim 1, characterized in that at least one anisotropically absorbing birefringent layer is formed of dichroic organic dyes of the polymeric structure.
6. The optical polarizer as claimed in claim 1, characterized in that at least one anisotropically absorbing birefringent layer is an oriented molecularly-arranged layer of organic salts of dichroic anionic dyes.
7. The optical polarizer as claimed in claim 1, characterized in that at least one anisotropically absorbing birefringent layer is an oriented molecularly-arranged layer

less than 0.1 mcm thick of dichroic dyes capable of forming a lyotropic liquid-crystal phase.

8. The optical polarizer as claimed in claim 7, characterized in that at least one anisotropically absorbing birefringent layer is an oriented molecularly-arranged layer of dichroic organic dyes of the polymeric structure.
9. The optical polarizer as claimed in claim 7, characterized in that at least one anisotropically absorbing birefringent layer is an oriented molecularly-arranged layer of dichroic dyes or their mixtures, capable of forming a stable lyotropic liquid-crystal phase.
10. The optical polarizer as claimed in claim 1, characterized in that at least one anisotropically absorbing birefringent layer has at least one refractive index that is directly proportional to the polarized light wavelength in at least some range of the operation wavelengths.
11. The optical polarizer as claimed in claim 1, characterized in that at least one anisotropically absorbing birefringent layer has the maximal value of at least one refractive index being not less than 1.9.
12. The optical polarizer as claimed in claim 1, characterized in that at least one anisotropically absorbing birefringent layer has the maximal absorption index of not less than 0.1 in the range of the operation wavelengths.
13. The optical polarizer as claimed in claim 1, characterized in that thickness of anisotropically absorbing birefringent layers is selected under the condition to obtain at output of the optical polarizer the interference minimum for one linearly-polarized light component and, simultaneously, the interference maximum for the other orthogonal linearly-polarized light component.

14. An optic polarizer according to claim 1, characterized in that it coprises at least two layers at least one of which is an anisotropically absorbing birefringent layer, and the other layer is an optically isotropic layer one refringence parameter of the birefringent layer being maximally different from the refringence parameter of the optically isotropic layer, and the other refringence parameter of the anisotropically absorbing birefringent layer coinsiding or being maximally close to the refringence parameter of the optically isotropic layer.

15. An optic polarizer according to claim 1, characterized in that it coprises at least two different birefringent layers at least one of which is an anisotropically absorbing birefringent layer one refringence parameter of the anisotropically absorbing birefringent layer being maximally different from one refringence parameter of the other birefringent layer, and the other refringence parameter of the anisotropically absorbing birefringent layer coinsiding or being maximally close to the other refringence parameter of the other birefringent layer.

16. An optic polarizer according to claim 1, characterized in that a light-reflecting coating is applied on one its side.

17. An optic polarizer according to claim 16, characterized in that the light-reflecting coating is metallic..

ABSTRACT

The invention relates to optics, particularly, to optical polarizers, that can be suitably used in liquid-crystal displays, polarizing spectacles, motor cars and other transportation means, as well as in glass used in construction, lighting fixtures and optical instruments.

Proposed is an optical polarizer including at least one birefringent layer having a thickness whereat an interference extremum is realized at output of the optical polarizer for at least one linearly-polarized light component, characterized in that at least one birefringent layer is the anisotropically absorbing one and has at least one refractive index that increases as the polarized light wavelength grows in at least some range of the operation wavelengths, thickness of the anisotropically absorbing birefringent layers is selected under the condition to obtain, at output of the optical polarizer, the interference minimum for one linearly-polarized light component and, simultaneously, the interference maximum for the other orthogonal linearly-polarized light component.

The result of the invention is that provided are high polarization characteristics of the optical polarizer in a broad spectrum range, whereby number of the used layers is not more than 10.

16 dep. Claims, 3figs.